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Distribution patterns of fire regime in the Pendjari Biosphere Reserve, West Africa

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Abstract: Pendjari Biosphere Reserve (PBR), a primary component of the W-Arly-Pendjari transboundary biosphere reserve, represents the largest intact wild ecosystem and pristine biodiversity spot in West Africa. This savannah ecosystem has long been affected by fire, which is the main ecological driver for the annual rhythm of life in the reserve. Understanding the fire distribution patterns will help to improve its management plan in the region. This study explores the fire regime in the PRB during 2001–2021 in terms of burned area, seasonality, fire frequency, and mean fire return interval (MFRI) by analysing moderate resolution imaging spectroradiometer (MODIS) burned area product. Results indicated that the fire season in the PBR extends from October to May with a peak in early dry season (November–December). The last two fire seasons (2019–2020 and 2020–2021) recorded the highest areas burned in the PBR out of the twenty fire seasons studied. During the twenty years period, 8.2% of the reserve burned every 10–11 months and 11.5% burned annually. The largest part of the reserve burned every one to two years (63.1%), while 8.3% burned every two to four years, 5.8% burned every four to ten years, and 1.9% burned every ten to twenty years. Only 1.3% of the entire area did not fire during the whole study period. Fire returned to a particular site every 1.39 a and the annual percentage of area burned in the PBR was 71.9%. The MFRI (MFRI<2.00 a) was low in grasslands, shrub savannah, tree savannah, woodland savannah, and rock vegetation. Fire regime must be maintained to preserve the integrity of the PBR. In this context, we suggest applying early fire in tree and woodland savannahs to lower grass height, and late dry season fires every two to three years in shrub savannah to limit the expansion of shrubs and bushes. We propose a laissez-faire system in areas in woodland savannah where the fire frequency is sufficient to allow tree growth. Our findings highlight the utility of remote sensing in defining the geographical and temporal patterns of fire in the PBR and could help to manage this important fire prone area.

Keywords: fire season; fire frequency; West African savannah; moderate resolution imaging spectroradiometer (MODIS); burned area

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1 Introduction

The structure, distribution, and functioning of terrestrial ecosystems worldwide are affected by natural and man-made fires (Bond et al., 2005; Scott et al., 2014). Many plants and animals rely on fire for their existence, and those that do not, such as rainforest and tundra species, are

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particularly sensitive to fire (DeBano et al., 1998). Fire is an important feature in savannah ecosystem globally and in combination with rainfall, soils, and herbivores density, they influence savannah distribution and stability (Scholes and Archer, 1997; Lehmann et al., 2011; Archibald et al., 2013). The combination of fine fuels in savannah and seasonal rainfall promotes fire-prone habitats in the ecosystem (Keeley and Rundel, 2005; Osborne, 2008). Fire regime over time, as well as a single fire occurrence in result, determine the ecological interaction of the ecosystem with the fire (Keane, 2019). A fire regime is described as the most typical frequency, season, intensity, severity, type, and area covered within an ecosystem (Bradstock, 2010). The fire regime is the spatio-temporal expression of various fire occurrences across time, influenced by the interactions of climate, fuel, vegetation, ignition pattern, and frequency at multiple scales (Agee, 1998).

A thorough understanding of the fire regime is required for the management of a fire-prone area (Archibald et al., 2017). Because each habitat or ecosystem is inextricably related to specific species, it is critical to conserve vegetation types and associated biodiversity through appropriate fire management. It has always been a priority for managers of the savannah ecosystem to understand and control savannah fires since fire regime varies and can have large consequences on savannah structure and function (Archibald et al., 2017). Wildfire statistics such as burned area, fire seasonality, fire frequency, and fire return interval are required for understanding the fire regime (Kasischke et al., 2002). Fire intensity and frequency are major controllers of tree demographics in savannah, and are generally what managers strive to maintain specific vegetation structure or composition (Archibald et al., 2017). Late and frequent dry season fires, because of their high intensity, can kill the natural regeneration including trees, even old ones (Ribeiro et al., 2017). Indeed, a fire return period of less than 2.00 a would be detrimental to the survival of tree and woodland savannah, which could evolve into shrub savannah (Frost, 1996; Chidumayo, 1997; Ribeiro, 2007). But a fire return interval of 2.00–4.00 a has been judged sufficient to enable woody vegetation to regenerate in areas where trees are destroyed by fire (Frost, 1996; Chidumayo, 1997; Ribeiro, 2007).

In contrast, the area burned and the season of burning can have repercussions for herbivore movements and nutrition, as well as soil resources, and are factors to consider when evaluating herbivore management objectives (Archibald et al., 2017). Fires in grass and shrub savannahs during the dry season promote fresh grass regrowth that is suitable for herbivore species (Eby et al., 2014; Pereira Jũnior et al., 2014). Fires also allow controlling the proliferation of forest regrowth in grass and shrub savannahs. Fire regime factors are interconnected, with season and frequency influencing fire intensity, fire intensity influencing fire size, and fire size influencing burned area and, hence, fire frequency (Archibald et al., 2017). A decrease or increase in the fire frequency can cause significant changes in the structure and composition of the ecosystem, leading to the biodiversity loss (Ribeiro et al., 2008; Tarimo et al., 2015). Savannah ecosystem managers need to deal with this complexity (Bond and Archibald, 2003), and an in-depth understanding of the interactions of biotic and abiotic ecosystem factors on fire dynamics and the consequences of fire on ecosystems are required for successful management of this widespread ecological process (Agee, 1997; Scott et al., 2014). Many protected area managers in Africa, America, and Asia assess fire regime in order to contribute to effective fire management (Lee et al., 2006; Kodandapani et al., 2008; Wittenberg and Malkinson, 2009; Asgary et al., 2010).

In the Pendjari Biosphere Reserve (PBR), like in most protected areas in West African savannah, mangers prescribed that burning is a common management tool (Takacs et al., 2021). PBR is a primary component of the W-Arly-Pendjari transboundary biosphere reserve, representing pristine biodiversity spot in West Africa (Sogbohossou et al., 2011). Wildfire is the main driver of the ecological process in the reserve, shape the landscape as well as species composition (Takacs et al., 2021). The lack of comprehensive and consistent fire records is a major challenge to addressing fire regime in the PBR. Fire spatial data are only available in a few isolated places where fire management strategies are in place. Remote sensing is nowadays a powerful tool to assess the fire regime. Satellite remote sensing enables to study the recent history

of burned areas over large ecosystem, providing useful data for analysing characteristics of the savannah fire regime, such as fire frequency. The mapping of burned areas from satellite images has been undertaken since the 1980s in the Brazilian Amazon (Santos, 1985; Setzer et al., 1994). The public domain contains burned area records from satellite sensors such as SPOT-VEGETATION, along track scanning radiometer (ATSR), and moderate resolution image spectroradiometer (MODIS). They give fire data with a medium geographical resolution and a very short time span. Because of its higher medium spatial resolution, Landsat and Sentinel data proved useful for dealing with fire regimes (Chuvieco et al., 2022). However, the low temporal scale may constrain studies of the fire regime, which must investigate the frequency, seasonality, and intensity of fires (Ribeiro et al., 2017). Here, we use multi-year data on fire occurrence in the PBR to improve the fire management strategy for the reserve. This study specifically aims to: (1) determine the spatio-temporal distribution of burned area; (2) evaluate the fire occurrence variations within and between years; and (3) determine the spatial distribution of fire frequency.

2 Material and methods

2.1 Study area

PBR is around 4711.4 km^2 protected area, which locates in the northwest of Benin (10°30′–11°30′N, 00°50′–02°00′E; Fig. 1). PBR is limited by the foothills of the Atacora massif in the east and by the Pendjari River in the north and west. The reserve has been upgraded to Biosphere Reserve in 1986 (Sogbohossou et al., 2011). PBR comprises a core area, the Pendjari national park covering 2660.4 km^2 and two adjacent hunting zones named "Konkombri" and "Pendjari" covering 1800.0 and 251.0 km^2, respectively. The climate is Sudanese-Guinean, with an uneven distribution of rainfall (Gnonlonfoun et al., 2019). Rain primarily falls during a single wet season from mid-April to mid-October, with a peak in August (Takacs et al., 2021). During the dry season, monthly mean rainfall across the PBR is less than 7 mm, whereas monthly mean rainfall at the peak of rain season is 250 mm during 1998–2018 (Takacs et al., 2021). The soils are ferruginous. The region is flat topography, and the altitude ranges from 150 to 200 m a. s. l. The vegetation of the PBR is a mosaic of grass and shrub savannahs, woodland savannah, dry forest, and riparian forest along rivers (Lopes et al., 2020; Fig. 1). The Pendjari River is the only significant one that runs through the reserve (Delvingt et al., 1989). PBR shelters several emblematic and endangered species of mammals such as African elephant, topi antelope or korrigum, kob, western hartebeest, African buffalo, waterbuck, hippopotamus, lion, leopard, cheetah, and many other wildlife species listed in Benin Red List. Currently, managers use early fires in November–December to promote regrowth and limit late fires that are mostly from anthropic origin.

2.2 Data collection

For the present study, we used MODIS monthly burned area product MCD64A1 v.6.1. The MODIS MCD64A1 fire data are a monthly worldwide gridded 500 m products that include per-pixel burned-area and quality data (Giglio et al., 2021). MODIS MCD64A1 detects estimated burning dates and maps the spatial area of monthly fires. The datasets were obtained for the period from October 2001 to September 2021 at the available website https://earthexplorer.usgs.gov/. We focused our analyses on twenty fire seasons from 2001 to 2021.

2.3 Data analysis

2.3.1 Spatio-temporal analysis of the fire regime

To capture the temporal and spatial aspects of fire regimes, we employed a mix of approaches. This methodological approach was based on the work of Smith and Wooster (2005), Archibald et al. (2010a), and Stellmes et al. (2013). In this study, fire regimes in the PBR were described by four indicators: burned area, fire seasonality, fire frequency, and mean fire return interval (MFRI).

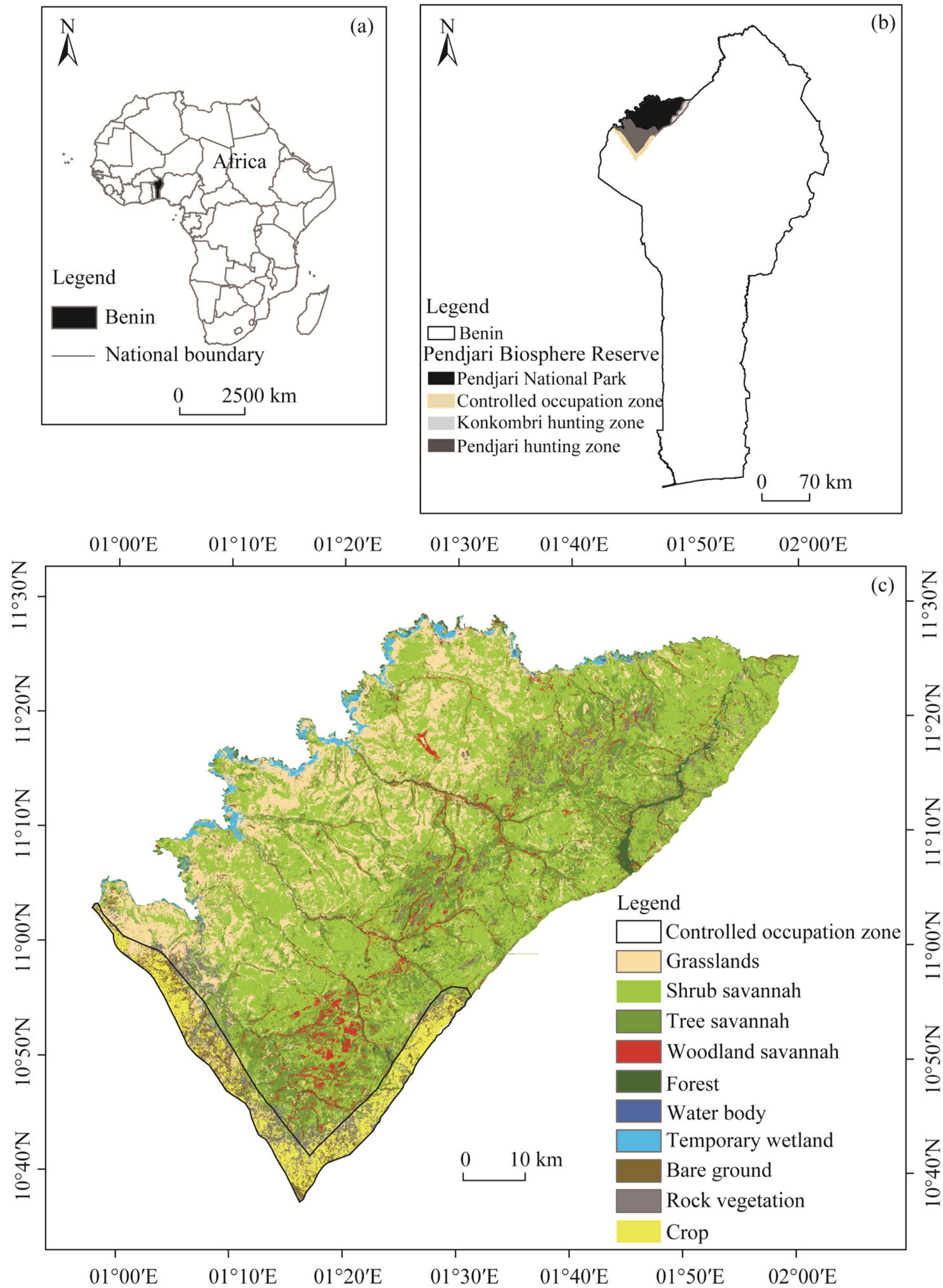

Fig. 1 Location (a and b) and land cover map (c) of the Pendjari Biosphere Reserve (PBR). Land cover map used is referenced from Lopes et al. (2020).

The yearly map of burned areas was produced by summarising the monthly burned area data collected from MCD64A1 products. The pixels in MCD64A1 product with a value between 1 and 366 (Julian days) were sorted into burned area per year and the corresponding dates were noted (Roy et al., 2008). The total area burned (km^2) was computed with the ArcGIS software v.10.4. We removed all invalid pixels from the dataset (clouds, water, and aerosols) (Archibald et al., 2010a; Stellmes et al., 2013).

To explore the burned area variations within and between years, we divided the fire seasons into three parts, namely early dry season (October–December), late dry season (January–April), and rainy season (May–September) according to the annual pattern of rainfall distribution in the

PBR (Houehanou et al., 2017). To assess the dynamics of fire throughout the year, we extracted the mean and standard deviation of the area burned per month for each period.

2.3.2 Fire frequency and MFRI

The number of fires that occur in a certain location over time is referred to as fire frequency. The number of times each pixel burned throughout the twenty years period was calculated by combining monthly burned area layers (Archibald et al., 2010a; Stellmes et al., 2013).

According to Ribeiro (2007), the MFRI is the experienced return time of a fire at a specific location, or the average number of years between two consecutive fires at a specific location, and was calculated using the following formula:

$$\mathrm{MFRI} = N \times \left(A / a\right), \tag{1}$$

where N is the period under study (20 a); A is the total area under study (km^2); and a is the total area burned during the period under study (km^2) (calculated as the sum of burned areas).

Annual percentage of area burned (APAB) is the average annual percentage of the study area burned. The APAB was calculated using the following formula:

$$\mathrm{APAB} = a / \left(N \times A\right). \tag{2}$$

The MFRI and APAB were calculated for the entire reserve and by land cover type.

2.3.3 Fire Return Interval (FRI) mapping

In order to analyse the spatial distribution of the FRI, we resampled the monthly burned area raster to 30-m pixel size. Then we combined monthly burned area to produce the burned area map for each year in ArcGIS v.10.4. Annual burned maps corresponding to total area burned were reclassified to produce an image with two grid codes (one for burned pixels and zero for unburned ones). Annual rasters were added to create a composite fire frequency map for the twenty years period corresponding to the number of times each pixel burned during the period. FRI (i.e., the average number of years between two fires event) was then obtained by using the raster calculator tool in ArcGIS v.10.4 with the following formula:

$$\mathrm{FRI} = N / \text{raster of fire frequency}. \tag{3}$$

The FRI map had 20 frequency grid codes corresponding to the number of times a fire returned to a particular area during the twenty years period. For example, a grid code with 1 as FRI frequency means that the area was burned each year while a grid code with 20 indicates areas burned only one time during the study period.

2.4 Statistical analysis

We tested the correlation between areas burned in early dry season and in late dry season during the 20 fire seasons using Pearson correlation test. Fire seasons were grouped into four periods, i.e., 2001–2006, 2006–2011, 2011–2016, and 2016–2021. It was considered separately for a 5-a cycle in order to take account of changes in total burned area. We compared the burned areas of early dry fire and late dry fire between the four periods with analysis of variations (ANOVA). We applied the logarithmic transformation to the burn area of early dry fire variable in order to follow ANOVA application conditions that are normality and homogeneity of variances. All statistical analyses were performed in R v.4.1.2 (R Development Core Team, 2021), with an alpha value of 0.05 as threshold for significance.

3 Results

3.1 Spatial-temporal distribution of wildfires

Fire season in the PBR extends from October to May with a peak in early dry season (November–December) (Fig. 2). Very few surfaces were burned in the rainy season only in May. Of the 20 fire seasons considered for this study, the average surface burned in May was 2.04 km^2. No surface was burned during the months of June–September over the 20 fire seasons considered.

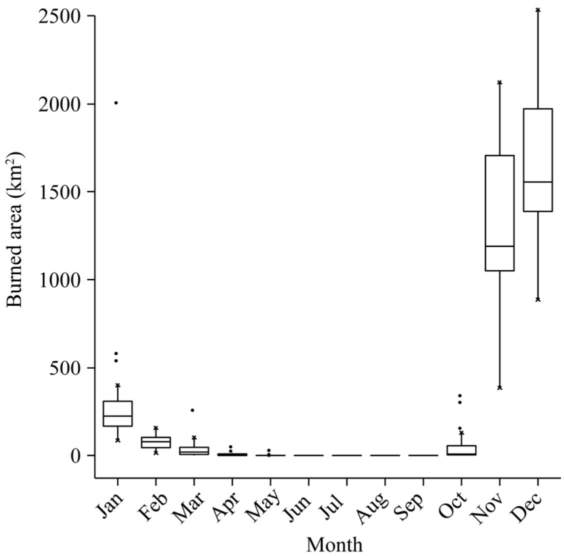

Fig. 2 Monthly distribution of fire in the Pendjari Biosphere Reserve. Boxes indicate the IQR (interquartile range, 75th to 25th of the data). The median value is shown as a line within the box. Outlier is shown as black circle. Whiskers extend to the most extreme value within 1.5×IQR.

There was a decrease in the annual total burned areas in the PBR over the two decades of fire season under study. However, the burned areas in the PBR increase and decrease over time alternately (Fig. 3). It has been observed that when the burned areas were low in one year, there was an increase in the following 1 to 3 seasons. The lowest burned area occurred in the season of 2017–2018 in the PBR (2983.00 km^2 burned area corresponding to 61.59% of the reserve). This was accompanied by a gradual increase in the areas burned in the following seasons with the last two seasons having recorded the most burned areas over the 20 fire seasons with respectively 4005.00 km^2 burned, i.e., 82.69% of the reserve during 2019–2020, and 4056.00 km^2 burned, i.e., 83.74% of the reserve during 2020–2021.

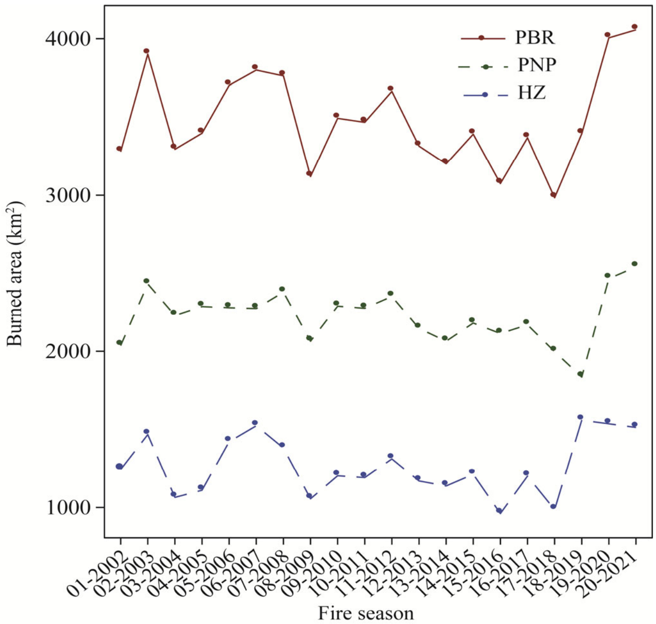

Fig. 3 Trend of burned area in the Pendjari Biosphere Reserve. PNP, Pendjari National Park; HZ, hunting zone. 01–20 are the fire seasons.

3.2 Fire seasonality

Fire occurrences in the PBR are seasonal and burned area varies accordingly. In the PBR, on average 62.30% of the reserve burned in the early dry season, while 9.58% of the reserve burned in the late dry season. The burned areas in early dry season and late dry season during the 20 fire seasons considered have had a sawtooth trend, while those burned in rainy season have had a linear pattern (Fig. 4). However, by observing the two curves of the early and late dry fires, we found that there was an inverse similarity in the appearance of the curves. The correlation test carried out between these two variables revealed, as expected, that there was a strong negative correlation (r= –0.74, P<0.05) between areas burned early and late in a dry season. Early fires therefore reduce the prevalence of late fires. The last two fire seasons (2019–2020 and 2020–2021) recorded the highest areas burned in the PBR out of the 20 fire seasons studied.

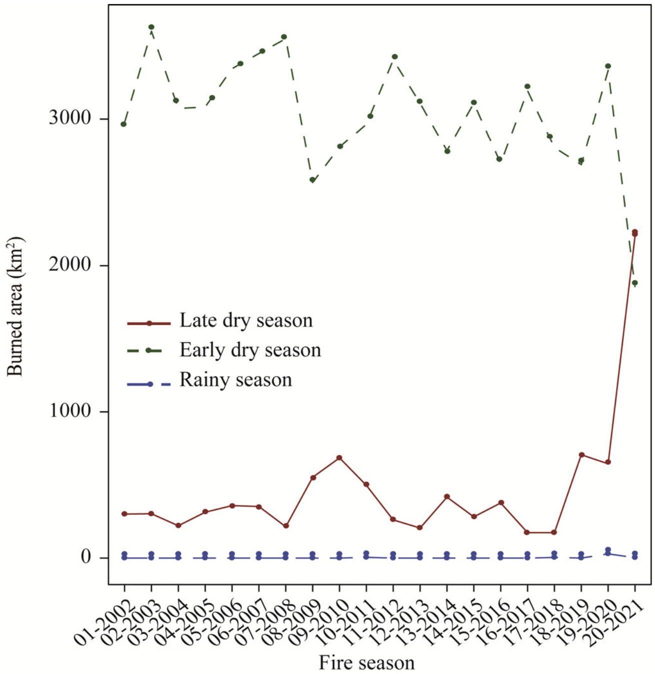

Fig. 4 Burned area in the Pendjari Biosphere Reserve according to the type of fire. 01–20 are the fire seasons.

By grouping the burned areas with five years cycle over the last 20 fire seasons, we found that there was a constant downward trend in early dry seasons (Fig. 5) without a significant difference over the four cycles (P>0.05). The early fire cycle of 2001–2006 had the highest average area burned while that of 2016–2021 had the lowest average area burned. Late burned surfaces showed an upward trend with a non-significant difference (P>0.05). The fire cycle of 2001–2006 had the lowest average area burned, while that of 2016–2021 had the highest average area burned in late dry seasons.

3.3 Fire frequency and FRI

Total area burned in the PBR during the twenty years period (2001–2021) was 69,688 km^2, which is equivalent to more than 14 times the size of the study area. PBR does not burn uniformly. The fire frequency varied from 0 to 24 over the 20 fire seasons considered. Few areas are therefore burned more than once during the same season. FRI indicates that fire returned to a particular site every 1.39 a and the APAB in the PBR was 71.94%. During the twenty years period, 8.21% of the reserve burned every 10–11 months and 11.52% burned annually or every year. Most parts of the reserve burned every one to two years (63.08%), while 8.28% burned every two to four years, 5.82% burned every four to ten years, and 1.89% burned every ten to twenty years (Fig. 6). Only 1.29% of the whole area did not burn during the study period. These unburned areas represent bare ground, water areas along the Pendjari River, and human occupation areas.

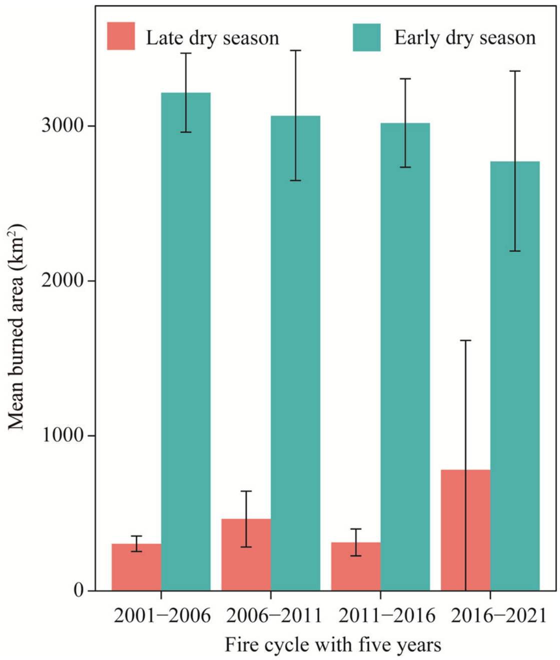

Fig. 5 Mean burned area in the Pendjari Biosphere Reserve with five years cycle from 2001 to 2021. Bars are standard deviations.

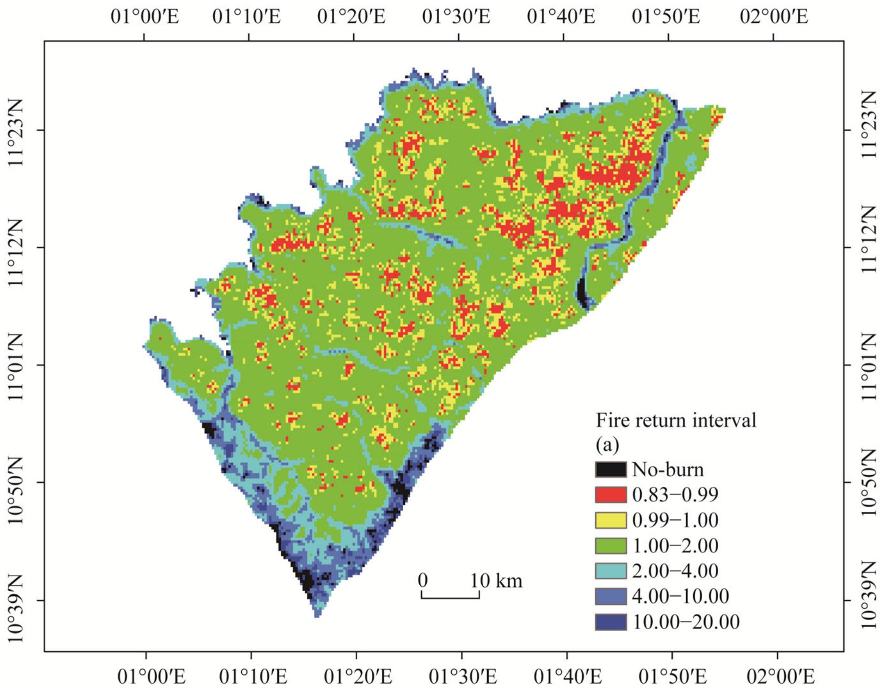

Fig. 6 Fire return interval (FRI) map in the Pendjari Biosphere Reserve

Fire frequency varied differently depending on the type of land cover (Table 1). Spatial distribution of the burned areas over the 20 fire seasons according to the types of land cover showed that the MFRI was low in grasslands, shrub savannah, tree savannah, woodland savannah, and rock vegetation (MFRI<2.00 a). The highest MFRI, 6.38 a, was observed in crop with low contribution to burned area (APAB=0.56%). APAB of shrub savannah, grasslands, and tree savannah had the higher values, being 41.04%, 14.58%, and 11.56%, respectively, which showed

the high contribution to burned area. The three land cover that had the lowest contribution to burned area was: forest, temporary wetland, and crop with APAB<1.00%.

Table 1 Fire frequency by land cover type in the Pendjari Biosphere Reserve

Type of land cover	Area		MFRI (a)	APAB (%)
	(km^2)	(%)		
Grasslands	885.12	18.40	1.25	14.58
Shrub savannah	2363.83	49.10	1.19	41.04
Tree savannah	736.81	15.30	1.31	11.56
Woodland savannah	168.69	3.50	1.40	2.49
Forest	105.65	2.20	2.23	0.98
Temporary wetland	82.27	1.70	2.41	0.70
Rock vegetation	135.96	2.80	1.85	1.51
Crop	172.83	3.60	6.38	0.56

Note: Bare ground (158 km^2 and 3.3%) and water body (3.22 km^2 and 0.06%) were not included. MFRI, mean fire return interval; APAB, annual percentage of area burned.

4 Discussion

Using remote sensing data, we have a better understanding of the fire regime in the PBR. Fires occur throughout the year in the PBR, but there is high spatial and temporal variability. Fire season in the PBR extends from October to May with a peak in early dry season (November–December). Fire occurrence and climate conditions especially temperature and precipitation are closely related (Machado et al., 2014; Silva et al., 2019). Fires depending on climate condition more when it is hot in absence of rain and high vapor pressure deficit of the atmosphere (Machado et al., 2014), and managers put fire at the beginning of the dry season then the period of peak. According to Takacs et al. (2021), who studied the factors that shape fire size and spread in the PBR, fires spread faster from November to February (early to mid-dry season) compared with October and the end of the dry season (March/April).

Our study also shows that there is a strong negative correlation between areas burned early and late in the dry season. The latter can be explained by the fact that the first fires (November–December) extremely reduce fuel availability in the landscape and thus the predisposition of the reserve to burn in the late dry season. The landscape is in a drying phase at the start of the fire season, with a reduction in grass and soil moisture (Mathieu et al., 2019). Although fires in early season are predicted to be less intense and perhaps less complete than that of late season (Govender et al., 2006), grass removal by the fires in early season can have several effects, including removal of grass scatter, reduced grass moisture and fire-induced soil moisture (Menges et al., 2004), all of which can help prevent late and catastrophic fires (Namukonde et al., 2017).

In the PBR, we observed that when the burned areas are low for one year, the occurrence of fire will increase during the following 1–3 seasons, displaying a cyclical trend. The studies of Ullah et al. (2013) in China show that the occurrence of fire is low in the first two years, it becomes high in the next three years, showing a five-year cycle. The cyclical trend of extreme fires and low fires observed can be explained by the fact that after a catastrophic fire having decimated the biomass in a given year, the ecosystem would take one to two years to reconstitute the vegetation cover sufficient for a second occurrence of intense fires (Gueguim et al., 2018).

There is a constant downward trend of fire in the early dry season and the increase in late dry season over the 4 cycles of five years. The result suggests that the early fires are used less and less, which favors the occurrence of the late fires. Indeed, the current management of the PBR from 2016 to now, tends to limit the use of management fires. Thus, the extent of fire in late dry season

that occurred during 2016–2021, with the largest area burned during 2020–2021 although the climate condition was similar to previous seasons, was due to the attempt of the reserve management to suppress fires and the consequent increase of dead and dry biomass, making it susceptible to the late fires. Grass biomass is mainly regulated by soil fertility and rainfall, but it is also affected by time since grass biomass accumulates from one year to the next in the absence of fire (Govender et al., 2006).

The entire PBR does not burn uniformly. The MFRI indicates that fire returned to a particular site every 1.39 a and the APAB in the PBR is 71.94%. During the twenty years period, most area in the reserve burned every one to two year (63.08%) and only 1.29% of the whole area did not burn during the study period. This result is similar to the values observed in Burkina-Faso protected areas, a savannah region in West Africa (Devineau et al., 2010), where yearly or biennal fires are the most predominant (47.40%). However, the MFRI (1.39 a; APAB=71.94%) in the PBR is lower than those obtained in West Arnhem Land, a savannah region of northern Australia, where the MFRI ranged from 2.70 to 2.80 a (APAB=36.00%–37.00%) (Oliveira et al., 2013), as well as that obtained in Jalapao State Park in Brazil, where the MFRI is 3.00 a (APAB=33.00%) (Pereira Jũnior et al., 2014) and in Niassa National Reserve, northern Mozambique, where the MFRI is 3.29 a (Ribeiro et al., 2017). All of these reserves have been using fire as a land management tool for decades. The West African savannahs are found in an arid/semi-arid area where the temperature is very high in the dry season with almost no rain and the quantity of fuel available is also greater, which results in the low return period. However, having found out that the reserve did not burn uniformly, we suggest that the MFRI must be analyzed in conjunction with its spatial distribution across the landscape for the good management decision.

Fire frequency varied differently depending on the type of land cover. The MFRI was low in grasslands, shrub savannah, tree savannah, woodland savannah, and rock vegetation (MFRI<2.00 a), and the MFRI>2.00 a in forest, temporary wetland, and crop with low contribution to burned area. The highest MFRI, was observed in the crop area surrounding the PBR. Southwestern part in control occupation zone registered the highest MFRI, 6.38 a with low contribution to burned area (APAB=0.56%). Farms, cleared area, and globally landscape with discontinuities, decrease the fire spread and the burned area size (Devineau, 1986; Clerici, 2006; Dolidon, 2007). Cultivation areas are associated with a strong human presence, which justifies the high MFRI, and therefore the low contribution to burned areas. In a follow up study, Archibald et al. (2010b) and Cangela (2014) found that human density was associated with reduced fire frequency. Shrub savannah and grasslands had the highest APAB (41.04% and 14.58%, respectively) coupled with low MFRI (1.19 and 1.25 a, respectively). This is due to a high accumulation of fuel in these habitats, which are burned during the fire season. Fire incidence was low in forest and temporary wetland because they are closed forest formations in humid habitats along rivers, and the fuel remains very moist throughout the year. In contrast, tree savannah and woodland savannah that are open vegetation with very dry fuel biomass, are affected by fires incidents during the fire season and therefore reduce the MFRI to less than 2.00 a. According to Frost (1996), Chidumayo (1997), and Ribeiro (2007), a FRI range between 2.00 and 4.00 a is needed to allow woody vegetation to grow in areas above the threshold, where they are killed by a fire. As tree species in woodland savannah have developed fire-resistant mechanisms, such as thick and/or corky bark, rapid early growth, and vigorous regrowth (Nefabas and Gambiza, 2007; Lawes et al., 2011), savannah fires rarely affect large trees, unless they have been previously damaged by animals (Shannon et al., 2011; N'Dri et al., 2014). However, late dry fires included a MFRI of less than 2.00 a in woodland savannah would eliminate forest regrowth and will be detrimental to the sustainability of the woody vegetation.

To preserve the integrity of the PBR, it is critical to maintain a fire regime that supports tree-grass interactions and allows for a balance between tree cover and diversity, as well as a grass supply available to herbivores. In this context, we suggest applying late dry fires two to three years after using early dry fires in shrub savannahs to limit the expansion of shrubs and bushes and so retain the integrity of the vegetation. We also suggest using early fire in tree

savannahs and woodland savannahs where the MFRI is less than 2.00 a to lower grass height and hence the supply of fuel in the environment. This enables trees to recover faster by releasing more nutrients and reducing grass competition (Govender et al., 2006). In locations where the fire frequency is sufficient to enable tree development (every three to four years), we recommend a laissez-faire approach (no interfering with the present fire regime). This management technique has been successfully applied in a number of other protected areas, including Kruger National Park in South Africa (Govender et al., 2006) and a forest management area in Kilwa, Tanzania (Mariki, 2016). These fire-prone landscape management practices can thus be applied elsewhere, but first the fire regimes in the landscape must be assessed. There are evidences that wildlife distribution in fire prone landscape is related to fire events (Reich et al., 2001; Eby et al., 2014). It is therefore important to maintain the good use of fire for management of protect area that will consider the holistic approach of conserving the sustainability of vegetation and wildlife.

5 Conclusions

This study show that remote sensing is a useful tool that can help to effectively monitor fire regime and therefore help to better manage fire in a fire prone landscape like the PBR. Fire season in the PBR extends from October to May with a peak in early dry season (November–December). Fire returned to a particular site every 1.39 a and the APAB in the PBR was 71.94%. The MFRI was low in grasslands, shrub savannah, tree savannah, woodland savannah, and rock vegetation (MFRI<2.00 a), while the MFRI>2.00 a in forest, temporary wetland, and crop area. Continued fire monitoring as well as determinating how wildlife select habitats in fire prone landscape will help to better design the fire management plan in wildlife reserves for the sustainable conservation of these animals that are intrinsically linked to the variations of landscape.

Conflict of interest

The authors declare that they have no known competing interests or personal relationships that could have appeared to influence the work reported in this paper.

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